orating and healthful. Our summers and autumns are usually very pleasant, the summers especially so, and with an appreciable absence of those two weeks of continuous and debilitating sieges of warmth that one encounters a little further southwest and south. To be sure our winters are long, but the cold is steady. The early portion of the spring is generally rather unpleasant, but I have experienced fully as bad, or worse, elsewhere.

Average temperature of spring months, 36.7°; summer, 62.8°; autumn, 43.4; winter, 14.2°. Average of the warmest spring, 44.4; warmest summer, 67.2°; warmest autumn, 47.3°. Average of the coldest spring, 30.9; coolest summer, 59.1°; coldest autumn, 39.1°; coldest winter, 6.2°. Spring months: March, April, and May; Summer: June, July, and August; Autumn: September, October, and November; Winter: December of previous year, January and February following.

Greatest number of days in any month, for twenty-six years, with minimum temperatures of zero or below: January, 24; February, 24; March, 12; November, 8; December, 19. Least number of days in any month with minimum temperatures of zero or below: January, 3; February, 0; March, 0; November, 0; December, 0.

Greatest number of days in any summer month with maximum temperatures of 90° or above: June, 1; July, 5; August, 2.

Number of years maximum temperature of 90° or above did not occur: June, 22; July, 12; August, 18; September, 23.

The minimum temperature usually falls to 32° or below, 168 times each year, and to zero and below 41 times.

Number of actual falls in temperature of 20° or more to 32° and below, twenty-six years' record: April, 6 times; May, 3; September, 0; October, 3.

NOTES BY THE EDITOR.

THE RAIN GAGE AND THE WIND.

On page 454 we give an interesting letter from G. J. Symons, Esq., the well known and most eminent authority on British rainfall, and in order that the influence of the wind on the catch of the gage may be more fully appreciated, we reprint the greater part of a study of the subject made by the Editor in 1887. This paper was read in full before the Philosophical Society of Washington, November 24, 1888. Some portions were published in the American Meteorological Journal in 1889-90, Vol. VI, pp. 241-248 and in Symons's Meteorological Magazine, Vol. XXIV, pp. 130-135, and in the Proceedings of the International Meteorological Congress at Paris, September, 1889, Vol. II, pp. 241-248. It was, however, not fully published until 1893, when it appeared as an appendix to Bulletin No. 7 of the Forestry Division of the Department of Agriculture. As the edition of that bulletin is now exhausted, and as the subject of this study is of the highest importance to others besides foresters, the present reprint will respond to the needs of all.

Mr. Symons writes that he has just started a Nipher shielded gage on the Cheviots on the flat top of a conical hill about 2,000 feet high, by the side of an ordinary gage which has been there four or five years; the records will probably begin to be published in about two years.

With regard to the accuracy of rainfall measurements viewed simply as comparable data, two matters have been studied experimentally, namely, the size and style of the gage and the altitude above ground. With regard to size it is satisfactorily shown that no error of more than 1 per cent systematically attaches to gages of the ordinary forms and of diameters anywhere between 4 and 44 inches. With regard to the altitude it must be conceded that for a hundred years it has been known in a general way that observations by gages at various heights above the ground are not comparable with each other. The remarkable influence of altitude was first brought to the attention of the learned world by Heberden, who, in a memoir in the transactions of the Royal Society of London, in 1769, stated that a gage on Westminster Abbey over 150 feet above the ground caught less than half as much as a gage at the ground. Since his day numerous others have instituted similar observations in their respective localities. Usually they have been satisfied with observing only one or two elevated gages, but of late years, in order to fully elucidate the subject, more elaborate measurements have been made; thus Phillips and Gray, at York, England, have observed at eight different altitudes including the gage on the tower of York Minster.

Bache, at Philadelphia, observed four gages on top of a square tower, and four others on poles above them; Col. Ward, at Calne House, Wiltshire, observed ten pairs of gages at elevations of 20 feet or less, each pair consisting of an 8-inch and a 5-inch gage; Bates, at Castleton Moor, similarly observed ten pairs of gages; Chrimes, at Rotherham Reservoir, six gages, at elevations of 25 feet or less; (——?) at Hawsker, four 3-inch gages, at altitudes of 10 feet or less; Wild, at St. Petersburg, six 10-inch gages, at altitudes of 5 meters or less, and one at an altitude of 25 meters. A very laborious series of six or eight gages at altitudes of 40 feet or less has, to my knowledge, been carried on for some years by Fitzgerald, at Chestnuthill, near Boston, but the results are not yet published.

It will be seen, therefore, that abundant observational data are at hand for the elucidation of the peculiarities of the rain gage, and the results that can be deduced from such data command our immediate attention. Whatever mystery has hitherto attached to the undoubted fact that elevated gages catch less rain is now fully explained away. This phenomenon is of the nature of an error in the rain gage depending upon the force of the wind that strikes it, and as will be seen, now that the knowledge of the source of error has been established, the method of correcting or preventing it becomes simple.

It will be remembered that Benjamin Franklin, upon reading Heberden's memoir, at once, in 1771, in a letter to Percival explained his results by the hypothesis that falling cold rain drops condense the moisture they meet with in the warmer lower strata, and that Phillips, in 1834, independently revived this hypothesis as explaining the increase of rainfall. A much truer explanation had been suggested by Meikle, in the Annals of Philosophy for 1819, and by Boace (Annals of Philosophy, 1822), to the effect that the deficiency is due to the velocity of the wind and to the fact that the gage stands as an obstacle to the wind; also Howard showed that the strength of the wind affected the higher gage. But these minor notices seem to have produced but little effect among the meteorologists, and it remains for W. B. Jevons, Phil. Mag., 1861, Vol. XXII, to demonstrate that the Franklin-Phillips hypothesis was highly unsatisfactory, and in fact impossible, and that the true reason for diminution of apparent rainfall with the height of gage is the influence of eddies of wind around the building and the mouth of the gage. This explanation had, however, been also quite clearly pointed out by Prof. Bache, who had shown that eddies around the top for the tower affected the distribution ofthe rainfall on the tower. Alexander Dallas Bache and Joseph Henry were intimately associated in their scientific work as early as 1835 (and especially after Henry came to Washington, in 1847), and the latter had adopted that which is now called Jevon's explanation, although as we have seen it was first given by Meikle, 1819, and subsequently independently arrived at by many others. This theory was definitely adopted and disseminated by Henry at least as early as 1853 in connection with his instructions to Smithsonian observers.

The essence of this explanation may be stated thus: In the case of ordinary rainfalls we invariably have the air full of large and small drops, including the finer particles that constitute a drizzling mist and the fragments of drops that are broken up by spattering. All these are descending with various velocities which, according to Stokes, depend on their size and density and the viscous resistance of the air; the particles of hail descend even faster than drops of water and the flakes of snow descend slower than ordinary drops. Now when the wind strikes an obstacle the deflected currents on all sides of the obstacle move past the latter more rapidly; therefore, the open mouth of the rain gage has above it an invisible layer of air whose horizontal motion is more rapid than that of the wind a little distance higher up. Of the falling raindrops the larger ones may descend with a rapidity sufficient to penetrate this swiftly moving layer, but the slower falling drops will be carried over to the leeward of the gage, and failing to enter it will miss being counted as rainfall, although they go on to the ground near by. Evidently the stronger the wind the larger will be the proportion of small drops that are carried past the gage; or again, the larger the proportion of small drops and light flakes of snow that constitute a given shower, the more a gage will lose for a given velocity of the wind. In brief, the loss will depend both upon the velocity of the wind and the velocity of the descent of the precipitation; therefore, a gage will in general catch less, in winter than in summer—less in a climate where light, fine rains occur than where the rains are composed of larger, heavier drops; less in a country or in a season of strong winds than of feeble winds; less when exposed to the full force of the wind by being elevated on a post than when exposed to the feebler winds near the ground.

The action of the wind in blowing the precipitation over to the leeward of the gage depends on velocity rather than on the square of the velocity of the wind and of the raindrop, and it is aggravated by the formation of whirls or eddies within the gage itself by reason of which light and dry snowflakes are even whirled out of the gage after being once caught in it. Similar remarks apply to the rainfall on the top of a large square building with a flat or depressed roof; not only does the top as a whole receive less than an equal area at the ground, but the distribution of rainfall on the roof is such that the least rain falls on on the windward portion and the most on the portion to leeward, while somewhere on the roof will be found a region whose average rainfall coincides with that on the ground. But the location of this region will vary with the direction and strength of the wind and the quality of the precipitation, so that we have but little assurance that any single rain gage on the roof will represent the rainfall on the ground.

An interesting illustration of this action of the wind has been noted by me in the case of several gages established in a cluster in the sandy region at Kittyhawk, N. C. The gages sat on the ground; their mouths were 2 or 3 feet above the surface, and being cylindrical they offered considerable resistance to the wind. The windward gages caught less rain than the leeward, but they also caught more sand, showing that the strong winds which carried the light raindrops on beyond also stirred up the light surface sand and were just able to drop the sand into the windward gages while carrying the rain on to the leeward gage. In accordance with the preceding explanation all observations everywhere show that the higher gages have the larger deficit in rain catch and still larger deficits in the snow catch, and that both deficits increase with the wind.

Mordecai states (Journal Franklin Institute, 1838, Vol. XXII, p. 37) that he arranged his observations at Frankfort Arsenal to show the rain catch at the ground and on the tower 52 feet high according to the force of the wind as estimated by him on the scale 0 to 10 as used by him, and found the deficit of the tower gage to be 0 per cent for calms and light winds, but increasing steadily up to 36 per cent for a wind of force 8.

Börnstein (Met. Zeit. Oct. 1884) arranged the catch in protected and unprotected gages according to the velocity of the wind, and for seven months of observation obtained the following deficits in millimeters, to which I add the same converted into percentages on the assumption that the protected gage is practically equivalent to the pit gage. This assumption, although it is not quite correct, will not greatly change our results:

TABLE 1.

Wind force 0 to 12	Number of days.	Protected gage catch	Unprotected gage.		
			Catch.	Deficit.	Deficit.
		Mm.	*Mm.*	*Mm.*	*Per cent.*
0	5	3.30	3.06	0.24	7
1	37	88.34	81.44	6.90	8
2	26	70.40	63.80	6.60	9
3	15	36.62	29.89	6.73	18
4	15	43.45	39.57	3.88	8
5	1	2.50	1.50	1	40
6	1	1.76	1.38	0.38	22

The distinction between the effect of the winds in heavy rains and fine rains is very clearly brought out by Börnstein's classification of the catch on twenty-six days of fine rain and forty-three days of heavier rains; the percentages are as shown in the following table:

TABLE 2.

Wind force.	43 heavy rains.		26 fine rains.	
	No. of days.	Deficit.	No. of days.	Deficit.
		Per cent.		*Per cent.*
0	....	....	4	23
1	17	6	8	25
2	13	13	6	18
3	7	14	6	46
4	6	17	2	52

Although all these preceding data, both by Mordecai and Börnstein, are limited in quantity, yet they conspire to show uniformly the same effect of the wind that is shown in an exaggerated scale when the ordinary gage is used to catch snowfall. Similar results based on a somewhat larger series of observations are published by Wild (Repertorium für Met., Vol. IX), as shown in the following Table 3, which gives the percentage of catch during the winter's snow and summer's rain separately for several altitudes and wind velocities:

TABLE 3.

Altitude.	Low wind velocities (2 to 5 meters per second).		High velocities (6 to 9 meters per second).	
	Rainfall (Apr.-Oct.).	Snowfall (Nov.-Dec.).	Rainfall (Apr.-Oct.).	Snowfall (Jan.-Mar.).
Meters.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0	100	100	100	100
1	95	89	94	80
2	92	86	84	82
25	81	26	56	16

These tables conclusively show the large influence of the wind on the catch of the rain, to say nothing of its influence on the catch of the snow. It is, therefore, evident that the annual rain precipitation, as shown by gages at various heights, although always diminishing with the altitude, will diminish in different ratios according to the peculiarities of the precipitation and the wind in that locality.

Without attempting to go into special refinements it will be sufficient for the present to study the annual catch as recorded at numerous stations. I have, therefore, in the following Table 4 arranged the results quoted by Wild (Repertorium Vol. IX, 1885,) and some others that have been published elsewhere. This table begins with the results of observations made at low altitudes, and of these I have taken the average of all observations made for four years at Calne, three years at Castleton, eight years at Rotherham, and ten years at St. Petersburg with gages of from 5 to 10 inches diameter. I have omitted the observations for two years at Hawsker with 3-inch gages, because of the shortness of the series and the smallness of the gage, which latter point has slightly exaggerated the percentage of loss. The combined result, therefore, for the 4 longer series is to show that for gages of such size and construction as are generally used in the weather bureaus of the present day, and for the average wind and snow or rain that occurs at these stations (which are in fact fair representatives of the northern portion of the temperate zone) the catch of rainfall diminishes with height of gage, as shown by the percentage in the last column, and in which, of course, the catch of the normal pit gage is adopted as the standard.

TABLE 4.

Location.		No. of years.	Altitude.	Relative catch.
			Meters.	*Per cent.*
			0	100
Calne	5 and 8-inch gages.	4	1	90
Castleton	5 and 8-inch gages.	3	2	88
Rotherham	5-inch gages	8	3	86
St. Petersburg	10-inch gages	10	4	85
			5	85
			6	84
London: Westminster Abbey		1	9	77
Emden		2	11	72
St. Petersburg: Central Observatory		1	13	68
York: Museum		3	13	80
Calcutta: Alipore Observatory		7	15	87
Woodside: Walton on Thames		1	15	73
Philadelphia: Frankfort Arsenal		8	16	95
Sheerness: Waterworks		3	21	52
Whitehaven: St. James's Church		10	24	66
St. Petersburg: Central Observatory		10	25	59
Paris: Astronomical Observatory		40	27	81
Dublin: Monkstown		6	27	64
Oxford: Radcliffe Observatory		8	34	59
Copenhagen: Observatory		4	36	67
London: Westminster Abbey		1	46	52
Chester: Leadworks		2	49	61
Wolverhampton: Waterworks		3	55	69
York: Minster		3	65	60
Boston: St. Botolph Church		2	79	47

For gages higher than 6 meters this table gives the results of the individual localities. If we consider the individual figures in the latter part of this table it would seem that the diminution of rainfall with elevation of gage is decided, but irregular; but it is proper to collect the data into a few mean values as shown in the following table, in which the last three groups may be considered to represent the average conditions of the precipitation in the temperate zone quite as fairly as do those of the lower altitudes:

If we may assume that on the average of the years and of the localities thus grouped together there is a fairly uniform average quality of precipitation, we should expect the deficiency at each altitude to have some definite relation to the velocity of the wind, and it emphasizes our conviction that the wind is the principal factor in bringing about this deficit when we find that these normal percentages are fairly represented by the simple formula: Deficit = 6 per cent of the square root of the altitude expressed in meters, or 3.9 times the square root of the altitude expressed in feet.. The adoption of the simple square root of the altitude is of course suggested by the well-known studies of Stephenson and Archibald, from which I infer that for these low altitudes the square root is a satisfactory approximation to the rate of increase of wind with altitude, while for much higher altitudes the one-fourth or other power might be preferable. The constant factor, 6 per cent, that enters this formula, will of course not be understood as applicable to other gages or velocities, or qualities of precipitation than those included in the above table, but the close agreement of the computed percentages of deficiency shows that we appear to be on the right track, and that some method must be devised by which to free rainfall measures from the influence of the wind at the mouth of the gage. We see, in fact, that the simple wind gage which we had trusted so long is liable to systematic error, whose magnitude is really enormous as compared with the small errors that we ordinarily investigate in connection with thermometers, barometers, and anemometers.

TABLE 5.

Group.	No. of stations.	Altitude.	Observed deficit.	Square root of altitude.	Computed deficit.	Observed, minus computed deficit.
		Meters.	*Per cent.*			
1	4	0	0	0.00	0	0
2	4	1	10	1.00	6	+ 4
3	4	2	12	1.41	8	+ 4
4	4	3	14	1.73	10	+ 4
5	4	4	15	2.00	12	+ 3
6	4	5	15	2.24	14	+ 1
7	4	6	16	2.45	15	+ 1
8	7	13	21	3.61	22	− 1
9	7	28	36	5.20	32	+ 4
10	5	59	42	7.68	46	− 4

ELIMINATION OF ERRORS DUE TO THE WIND.

Two methods are open to us by which to eliminate this error of the rain gage. One is instrumental, the other observational.

Instrumental methods—As before said, Professors Bache and Henry seem, from their own observations, to have clearly apprehended the nature of the error with which the gage is affected, and the latter was quick to suggest the remedy, namely, to so construct a gage that it shall closely imitate the conditions of the normal exposure, or that of a gage whose mouth is on a level with the ground, and which is, therefore, not covered over by the disturbing swift currents and eddies. The records of the Smithsonian show that Henry caused numerous experiments on this subject to be conducted after he and Espy, in 1848, inaugurated the Smithsonian system of meteorological observers. In the second volume of Henry's collected writings, the reader can easily consult his discussion of the erroneous explanations and his own correct explanation of the phenomenon, and at page 262 will be found Henry's suggestion of "the shielded gage." This shielded gage was an ordinary small cylindrical gage; a few inches below the mouth of this gage a horizontal circular plate of tin 4 or 5 inches wide was soldered to it like the rim of an inverted hat; by this means he hoped to ward off the disturbing eddies which would necessarily be formed almost wholly beneath the flat rim and therefore harmless.

Although Henry's shielded gage was described at least as early as 1853, yet I have not found as yet any records of observations made with it, though such probably exist, as Henry's suggestion was widely distributed among the Smithsonian observers.

In 1878 Professor Nipher, of St. Louis, published the first results of his observations with his own shielded gage, as independently invented by him. He surrounds the upper portion of the gage by an umbelliform screen made of wire gauze; the falling rain strikes on this and breaks up, and falls down to the ground without spattering into the mouth of the gage at the center, while the gauze sufficiently breaks up the wind currents to maintain a normal condition of the air at the mouth of the gage. Nipher's own experiments with this gage showed that its catch at a height of 118 feet above the ground was nearly the same as that of the ground gage itself.

The invention of the shielded gage gives us the required instrumental solution of our problem. Of late years Börnstein, in Berlin, and Wild, in St. Petersburg, have experimented very largely with Nipher's shielded gage and have reported in its favor. Hellmann, during 1887, also observed with a Nipher gage, and finds the effect of the shielding to be very favorable, but not so much so as to make it quite equal to the ground gage.

The good accomplished by the shields adopted by Henry or by Nipher can also be largely attained by a simple system of protection from wind. By "a protected gage" I mean an ordinary gage whose mouth is a few feet above the ground and which is surrounded, at a distance of a few feet, by a fence or screen separate from the gage and whose top is a little above the mouth of the gage. The protecting fence is, therefore, so arranged that it diminishes the wind at the mouth of the gage without itself introducing new and violent injurious eddies. Börnstein, Wild, and Hellmann have experimented with such protected gages, the protecting fence being so constructed that the angular altitude of the top of the fence as seen from the mouth of the gage is between 20° and 30°. The catch of the gage thus protected always exceeds that of the free gage, so that the correction to reduce it to the ground gage is comparatively quite small, the deficit being reduced from 25 per cent down to 3 or 4.

Hellmann has also made the following interesting experiment: The roof of the Academy of Architecture in Berlin, where the Royal Prussian Meteorological Institute is temporarily domiciled, covers about 50 meters square, and is not merely flat, but depressed considerably below the rampart walls of the building. It, therefore, constitutes a grand protection to any gage placed near the center of the roof, and accordingly Hellmann finds that in this location gages catch more than anywhere else on the roof or the ramparts, and but little less than a gage on the ground. His conclusion is that the Nipher, or similar protection, can nearly, but still only partly, annul the injurious influences of strong winds on the catch of the gage.

The reduction or correction of rainfall for altitude, as it has hitherto been called, is, therefore, really a correction or reduction of the readings of the rain gage for an instrumental error due to the wind.

Observational methods.—As an observational method of obtaining the true rainfall from the gage reading, when it is impracticable to establish a normal pit gage in a good location, or when it is desired to determine approximately the correction to be applied to past records obtained from a gage that still remains in the former place, the following arrangement offers a fair approximation:

If the present gage has been standing in an open field at a few feet elevation, place two or more *similar gages* near it, and similarly located as far as obstacles are concerned, except only that one of these is to be decidedly lower than the old one and the other decidedly higher. From a comparison of the simultaneous records of any two gages and their altitudes, we should for each separate rainfall, rather than for the monthly and annual sums, deduce the normal rainfall by the solution of two or more equations of the form:

Observed catch of gage $= (1 - x\sqrt{\text{altitude}}) \times$ (desired catch of normal pit gage).

Where x is the unknown special coefficient of deficiency due to wind at that altitude. Having two gage catches, c_1 and c_2 for the two altitudes H_1 and H_2, we may represent the true rainfall (R) by the formulæ:

$$c_1 = (1 - x\sqrt{H_1})\,R$$
$$c_2 = (1 - x\sqrt{H_2})\,R$$

whence

$$R = \frac{c_1\sqrt{H_2} - c_2\sqrt{H_1}}{\sqrt{H_2} - \sqrt{H_1}} = c_1 + \frac{1}{\sqrt{\frac{H_2}{H_1}} - 1}(c_1 - c_2) = c_1 + n(c_1 - c_2).$$

If c_1 and H_1 relate to the lower gage we shall generally have $c_1 > c_2$ and $H_1 < H_2$ and the coefficient n will be a positive fraction, whose value is given in the following table for such combinations of units as may easily occur in practice.

TABLE 6.

Values of n.

Altitude of upper gage.	Altitudes of lower gage.				
	1	2	3	4	5
2	2.414				
3	1.366	4.450			
4	1.000	2.414	6.469		
5	0.828	1.721	3.438	8.474	
6	0.689	1.366	2.414	4.450	10.485

If the present gage be located upon the top of a building, perhaps the best that can be done to study the accuracy of its records is to locate other similar gages so as to get the average rainfall over the whole roof at the same uniform altitude; the next best would be to establish a standard protected or shielded gage as high as practicable above the roof.

If a new observing station is to be started then a single shielded or protected gage is better than a single unprotected one; but two more shielded gages at different altitudes afford the means of calculating the correction for wind which will, of course, be quite small for this style of gage.

VARIATIONS IN GEOGRAPHICAL DISTRIBUTION OF RAINFALL.

By the combination of records from widely separated rainfall stations we ordinarily seek to determine the uniformity or irregularity of rainfall as to its geographical distribution. The study of horizontal distribution of rain should be first made by means of simultaneous observations at many stations within a small region. The most instructive work of this kind that I know of is that just now being carried on by Hellmann in the "experimental rainfall field" of the Royal Prussian Meteorological Institution. This institution was in 1884 officially transferred from the bureau of statistics, where it had been organized by Mahlmann and Dove, over to the bureau of religion, education, and medicine, where it is now intimately connected with all the scientific and educational work in Berlin and is under the directorship of Prof. W. von Bezold. The experimental rain field really consists of the City of Berlin and the country around, especially to the westward, embracing a region of about 15 kilometers square, within which are located Berlin, Spandau, and Potsdam The forests on the westward, the intermediate gardens and fields, the valley of the River Spree, and the City of Berlin, offer a great variety of surfaces but without any mountains or hills. The average height of the ground above sea level is scarcely 50 meters, the average distance of the gages from each other, namely, the mean of all possible combinations is about 4.5 kilometers, the maximum distance being 11 and the minimum 0.5.

Within this area Hellmann has twenty-one stations, some of which represent several gages. His work began in 1884, and he adopted as the standard height of the mouth of the gage 1.07 meters above the ground. I have selected for study the eleven stations for which complete records for 1886–'87 are given in Hellmann's Reports. The accompanying Table 7 shows the rainfall for each station for each year and the departures of each station from the annual mean of the eleven. From these departures we get the probable error of any one annual rainfall as plus or minus 6 per cent of its own value. That is to say, assuming that the same quantity of rain and snow fell uniformly over the whole of this small region and that the gages, if unaffected by any error, should therefore agree among themselves perfectly, then their failure to do so is such that it is an even chance that any given rainfall is discordant from the average by plus or minus 6 per cent. At first Hellmann suggested that the records of stations 1, 2, 3, and 4, which were in the open land east of the forests, showed that less precipitation fell there than over the forests, affording an argument for the idea that the forest attracted an extra amount of rain; but of the other stations there were also some that were protected by the forests, and next year all of these reported large rainfalls. Now all of these gages were at a standard height in open regions such that only the variations in wind proper or in the currents induced by neighboring obstacles could conceivably affect the catch of the gage; moreover the differences between the stations were greatest in the winter and least in the summer months. All his study of the configuration of the ground around the stations tends to show that the differences in the catches of the gages were due to the irregularities of horizontal distribution of the strength of the wind as influenced by the surroundings. In other words, instead of studying geographical or horizontal distribution of the total annual rainfall it is safe to assume that this had been uniform for each year over this small area, and that we are studying simply the horizontal distribution of a deficiency in catch, or a rain-gage error due to very local winds at the mouths of the gages.

TABLE 7.

Station, Hellmann's number.	Observed precipitation.		Departures.			
	1886.	1887.	1886.	1887.	1886.	1887.
	Mm.	*Mm.*	*Mm.*	*Mm.*	*Per ct.*	*Per ct.*
1	394	514	30	4	7	1
2	363	507	61	11	14	2
3	387	524	37	6	9	2
4	388	505	36	13	9	2
6	435	492	11	26	3	1
7	438	536	14	18	3	1
8	462	549	38	31	9	2
9	462	509	38	9	9	2
10	473	536	49	18	12	2
12	444	516	20	2	5	1
14	422	516	2	2	0	0
Mean	424	518	336	140	....	....

This conclusion is confirmed by examining the records in the summer months separately from those in the winter. Local showers are frequent during the summer and the irregularities in horizontal distribution are presumptively greatest at that time. During the winter the extended layers of clouds give us no *a priori* reason to expect large irregularities in the geographical distribution of snowfall and rain. Hellmann's records show that the geographical irregularities in the catch of his gages is really least in summer and greatest in winter, thus confirming our convictions that on the average of the year the precipitation is uniformly distributed and the variations in catch depend on the irregular distribution of the wind at the mouths of the gages during the fall of rain and snow.

The eleven gages here selected from Hellmann's data were unprotected and uniformly 1.07 meters above ground, and it is evident that they would not have necessarily shown a similar discrepancy of 6 per cent among themselves had they been placed at some other altitude. As the absolute deficits of each gage increase like the wind with the square root of the altitude, so also should the apparent irregularities in geographical distribution. But this rule should not be so far stretched as to assume that gages at the ground surface would therefore show no irregularities in the horizontal distribution of rain, the fact being that there is even for them an outstanding uncertainty of 2 per cent, which is the total combined effect of all the irregularities of measurement and the drifting of snow or rain.

In general, then, we conclude that in the case of a number of gages placed within a few miles of each other, and of which we know nothing as to the height and exposure, except that in general the observers have placed them in fairly open situations, there is no reason to give a preference to the reports of one gage rather than that of another, since if the observers are equally reliable the irregularities of catch are likely to far exceed the errors of careful observers. Again, the probable error of 6 per cent, due to unobserved and uncontrollable irregularities in the action of the wind on these ordinary cylindrical gages located 1.07 meters above the ground, indicates the utmost limit to which any attempt at refinement in drawing annual isohyetal lines should be carried at present, at least in climates such as that of Berlin, and until the data are corrected for wind effects. Finally, any attempt to deduce from such gages the relative rainfall over the forest, the cleared land, the hill and the valley, can only be successful in so far as we make due allowance for the influence of the wind and the character of the precipitation.

CHRONOLOGICAL VARIATIONS OF RAINFALL.

What has just been said with regard to geographical distribution holds good equally with regard to the chronological variations in rainfall. Undoubtedly there are years of large and of small precipitation, but if we analyze these years we shall see that they differ, not only in the quantity, but at the same time in the quality of the precipitation and in the force of the winds. Until we are able to correct the measured rain or snow for the wind effect we must include this large source of uncertainty in the catalogue of errors to which our measurements are subject; thus, in some years, there may be a heavy snowfall of very light snow flakes falling during strong wind, and in spite of all our efforts to estimate we get too small a record. Again, if we confine ourselves to the summer rains only, namely, those that directly affect the growth of plants, we shall find that in almost every long-continued series of observations at any locality trees, houses, and other obstacles have gradually grown up in the neighborhood so that the average wind force at the gage has undergone a steady progressive diminution and the gage, therefore, catches a larger percentage at the close of the series than at the beginning, unless the obstacles were always so near as to shelter the gages. I have computed the departure of each annual total precipitation (rain and snow) from the mean of forty-six years at Fort Leavenworth, Kans. (using post-surgeon's record only); of twenty-two years at Spiceland, Ind. (observations by H. R. Dawson), and forty-two years at Washington, D. C. (observations at the Naval Observatory). From the mean of these departures it is easy to compute the so-called probable error or departure for any one year, or the index of variability of annual precipitation. The results are given in the accompanying Table 8, and are interpreted in the following paragraph:

TABLE 8.

Stations.	Number of years.	Average total annual precipitation.	Probable error of annual precipitation.		Probable error of mean of 49 years.	
		Inches.	*Inches.*	*Per cent.*	*Inches.*	*Per cent.*
Leavenworth	46	32.48	6.02	18	0.86	2.6
Spiceland	22	39.40	5.47	14	0.78	2.0
Washington	42	39.48	5.20	13	0.74	1.9

The mean annual catch at the Fort Leavenworth gage is 32.48 inches, as given by forty-six years of observations, which, however, differ among themselves from year to year so much that it is an even chance that the catch of any one year will differ from this mean by more or less than 18 per cent of its value, or by 6.02 inches; this 18 per cent is in part due to actual irregularities in rainfall, and in part to the variable effect of the wind and the irregular proportions of snow and rain; the actual rainfall is larger than this catch by an unknown amount depending on the character of the precipitation and the strength of the wind at mouth of the gage.

It is, therefore, evident that any conclusion as to a change of climate during these years involving quantities less than the probable errors of the mean rainfall must be entirely illusory.

RECOMMENDATIONS.

Our study of the rain gage and its errors would have a melancholy conclusion, did it not afford us some suggestion as to the proper methods of determining and allowing for these errors. In view of our present knowledge we now see that in establishing new stations better methods of exposure should be adopted, and such as are in fact very different from those that have hitherto been considered allowable. We must closely imitate the conditions prevailing at the average surface of the ground, that is to say, in the order of preference the exposure would be: (1) the pit gage; (2) the protected or the shielded gage near the ground; (3) several protected or shielded gages distributed over a flat roof; (4) the shielded gage on posts considerably elevated above slanting roofs. Moreover, in no case should a single gage be relied upon, but in all cases at least two similar gages at very different heights should be observed. From the records of these two gages we can compute the catch of the normal pit gage by the formula previously given.

As this formula is also applicable to the ordinary, and in fact to any form of gage, we furthermore see that an approximate correction, needed to reduce valuable past records to the normal gage, may now be determined, if these old gages are still being recorded, by at once establishing near them two or more similar gages at considerably different heights; from the records of all these gages for the next few years we may determine, at least approximately, a correction applicable to the past years of historical records. Finally, we are warned against attempting to draw from past records conclusions that are finer than the data will justify.

METEOROLOGY BY THE LABORATORY METHOD.

The November number of Popular Astronomy contains the following admirable article on the teaching of astronomy, which applies equally well to meteorology and is to be commended to all teachers and students.

If by the laboratory method is meant such observation and investigation of selected phenomena pertaining to any subject as shall yield to the student an abundance of essential facts—if it mean that from the many such related facts reasonable explanations of these phenomena may be expected from the student who thinks simply and logically—if it be a manner of so presenting a subject through its phenomena to the mind of a student that he may reach out toward conclusions of a general nature, to the principles and laws which pertain to that subject, as a direct sequence of his own observations and thought processes—if these be the aims of laboratory methods of teaching, then astronomy [and meteorology] may be thus taught, and demands such manner of presentation to the students of our secondary schools.

It is far from our purpose to pose as an instructor in pedagogy, or to enter upon any psychological discussion whatsoever. Yet it were pardonable, surely, to restate as a cardinal principle of educational work that mental growth results only from mind activity rightly directed. As the highest and best of the physical being demands that every muscle have its exercise and development, so the mind in its every capacity is to be exercised.

One stage in the development of the science of education was content to have the student memorize the words of the text regardless of any full comprehension of the thought expressed therein. It was a great step in advance when mastery of the thought of the author was made of prime importance, and the expression of that thought in the words of the student himself was encouraged or required. There remained a single step further, and with many a teacher it has yet to be taken in the full round of the science work, the *requirement of original thought from the student* as well as original expression of thought. To require of students in our secondary schools in study of any science nothing further than mastery of the thought of an author as expressed in the text book is neither the most complete nor the most profitable mental activity.

Allowing that we have in books veritable storehouses of the riches of ages of human experience, thoughts that are profound, language that is grand, thought expressions to whose depths and to whose heights we may scarcely hope to attain, expressions that may tax to the uttermost our endeavors of a lifetime to rethink them, humble travelers as we are over well marked mental highways and byways—allowing all this, it is contended that the great mass of books put into the hands of our students are *not of this character*, and that the writers of modern text-books for secondary schools are few who seek to do other than to put before the student in the simplest, most elementary manner possible the facts of the subject treated. It is the facts themselves and the manner in which they are presented that is of prime importance. Any course in science that stops short of requiring original thinking by the student, thinking that is based upon facts that are leavened through and through with the results of personal observation and investigation must needs be comparatively barren of mental growth and vigor.

The logical result of such views is to regard the text-book in science as a reference book in simple compact form, furnishing what shall be needed to supplement the results of the student's own efforts in observation and thought—a reference book differing not a whit in purpose from the other reference books found in any well appointed laboratory save in its larger use and *that it is the students'* own.

Happily the day was soon past when the science student of our secondary schools was looked upon as a discoverer, as one who by his unaided efforts was to re-establish the laws, principles and theories of the subject he pursued and all this as a result of his own investigations. the story of Agassiz, his student and the fish, was made to teach preposterous lessons. In most of the sciences the limits of original investigation are well defined, the need and use of text and reference books well established in supplementing laboratory work. In astronomy [and meteorology], however, oldest of the sciences, science of the material universe, the student is too often expected to know nothing save what his author tells him, to cultivate no mental powers in its study save the taxing of an already over burdened memory; or, at most, his powers are taxed in making out what the author means in his text, and through the exercise of the imagination in picturing what the author describes as existing.

In any attempt to apply the laboratory method to the teaching of astronomy [and meteorology] there is the same necessity as in the other sciences that no time be wasted upon comparatively unimportant phenomena; that observation shall be so carefully directed as to readily acquire the desired facts; and that these results shall be so related as to make generalization possible. That there are difficulties in the way is true, but they may largely be included under these heads: (1) A failure on the part of many teachers to appreciate the fact that although many of the phenomena of astronomical [and meteorological] science require apparatus too expensive and too complicated to be available, and although many of the conclusions are reached through reasoning too abstract to be within the comprehension of the students to be instructed—there still is wide range for observation and inference fully within the comprehension of pupils of high school grade: (2) The text-books in astronomy [and meteorology], with but an exception or two, not only tell all the facts that the student can easily acquire for himself under direction as well as those beyond the range of his ability and opportunity, but, withal, their pages are crowded with ready made inferences from these facts, making it wholly unnecessary for the pupil to do any thinking himself beyond that involved in language interpretation. He may study astronomy and complete his course, but still has no more knowledge of the relation of his work to celestial phenomena than one who studies the bookkeeping of the high school instead of the actual business conditions it is supposed to exhibit. Science teaching in any grade of school work should surely not make memory and imagination a first consideration—observation and thinking a secondary matter.

When teachers of astronomy [and meteorology] shall be content no longer to instruct in this science upon a basis so radically different from that of the generally recognized laboratory sciences, and shall demand for laboratory reference text books that are filled with facts clearly and logically arranged, and having terse statements of the theories advanced therefrom, together with such descriptions and explanations as are beyond the ability of the average student for whom they are written, but which at the same time are free of all such matter as may properly be required of students as the result of their own observation and thinking—when teachers shall demand that guides and manuals for the study of astronomy [and meteorology] shall be furnished even as in physics and in chemistry, to the end that like principles of instruction and of laboratory procedure may be applied to all alike—then, and not till then, will publishers come to the relief of such teachers as already seek to secure in the teaching of astronomy [and meteorology] in secondary schools the fullness of its possibilities for mental development, even as with other sciences, in addition to its value otherwise so fully recognized.

THE RECURVING OF HURRICANE TRACKS IN THE NORTH ATLANTIC.

The Pilot Chart for November, published by the United States Hydrographic Office, gives a diagram showing the path followed by the centers of twenty-five tropical cyclonic storms in the North Atlantic Ocean during the ten years, 1890–99. Concerning these Mr. James Page, of that office, makes the following remarks:

Of these storms Nos. 2 and 9 each pursued a course trending between north and west, the former crossing Florida into the Gulf of Mexico, the latter disappearing over the mainland in the vicinity of Charleston. The course of Nos. 10 and 16 was in a northeasterly direction throughout, although it is probable that the complete history of these storms would show an earlier movement toward the northwest. The absence of observations, however, precludes in either case any attempt to represent this earlier portion of the track. No. 20 followed an almost due northerly course, keeping well under the coast, and No. 21, although the barometric depression accompanying the storm originated in the Gulf of Mexico, failed to attain full hurricane violence until reaching the position indicated.